

Fabrication of Functionally Graded Hybrid Composites

TEAM MEMBERS

Texas A&M University

Ibrahim Karaman (Mechanical Engineering)

Zoubeida Ounaies (Aerospace Engineering)

Miladin Radovic (Mechanical Engineering)

University of Illinois – UC

Scott White (Aerospace Engineering)

**University of Dayton
Research Institute**

Khalid Lafdi (Mechanical and Aerospace Engineering)

Virginia Tech

Dan Inman (Mechanical Engineering)

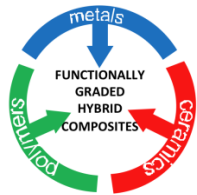
Stanford University

Fu Kuo Chang (Aeronautics and Astronautics)



**AFOSR-MURI
Functionally Graded Hybrid Composites**





Functionally Graded Hybrid Composites (FGHCs) – The concept

Materials

Oxide ceramic
Functionally
graded ceramic/
metal composite
(**GCMcC**)
Polymer matrix
composite
(**PMC**)

MAX Phase Metal layer (Ti or SMA)

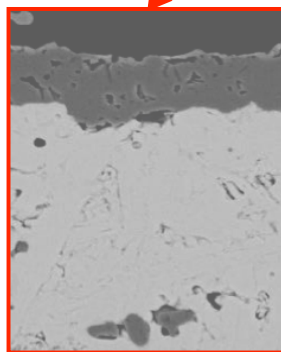
~ 1000°C

~ 400°C

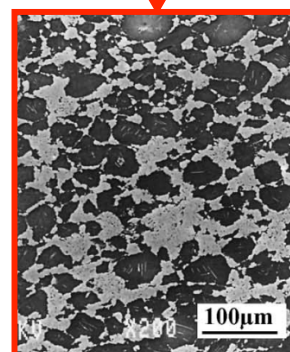
Function

Thermal/Environmental Barrier
Coating (Al_2O_3 , ZrO_2 , PS- ZrO_2)
Self-healing of Protective Coating
Gradual Change in Thermal Expansion
Thermal Management
Mechanical Damping
Compressive Stress on Ceramic
Load Bearing
Host Sensors
Damage Propagation Barrier

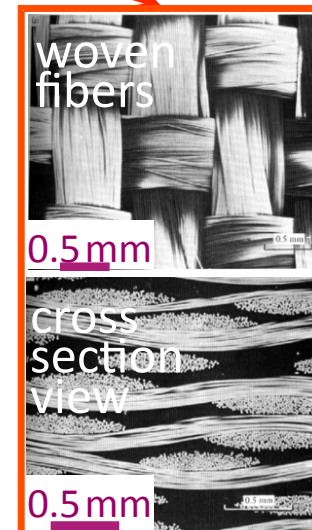
self-healing
damaged
protective
oxide
surface



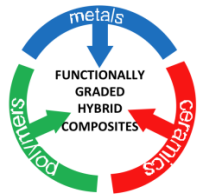
15 μm thick protective Al_2O_3
surface layer formed after 10,000
heating cycles of Ti_2AlC



Ti_2AlC (light) + γTiAl (dark) as
an example of MAX phase
composite. (Produced by *Spark
Plasma Sintering*)



Actively Cooled
PMC with
microvascular
cooling
functionality
and/or High
Temperature
PMCs with
polyimide
matrices



Functionally Graded Hybrid Composites (FGHCs) – The team

Fabrication of Graded Ceramic Metal Composites (GCMcCs)

Radovic (TAMU – Ceramics and MAX phases)

Karaman (TAMU – Ti alloys and SMAs)

Fabrication of Polymer Matrix Composites (PMCs)

Actively Cooled High Temperature PMCs

White (UIUC), Ounaies (TAMU)

Joining of GCMcCs with PMCs

Ounaies, Radovic, Karaman (TAMU)
Lafdi (UDRI)

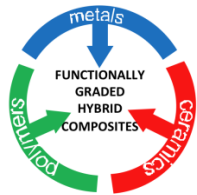
Embedding SHM modules and networks

Inman (VTU) Chang (Stanford)



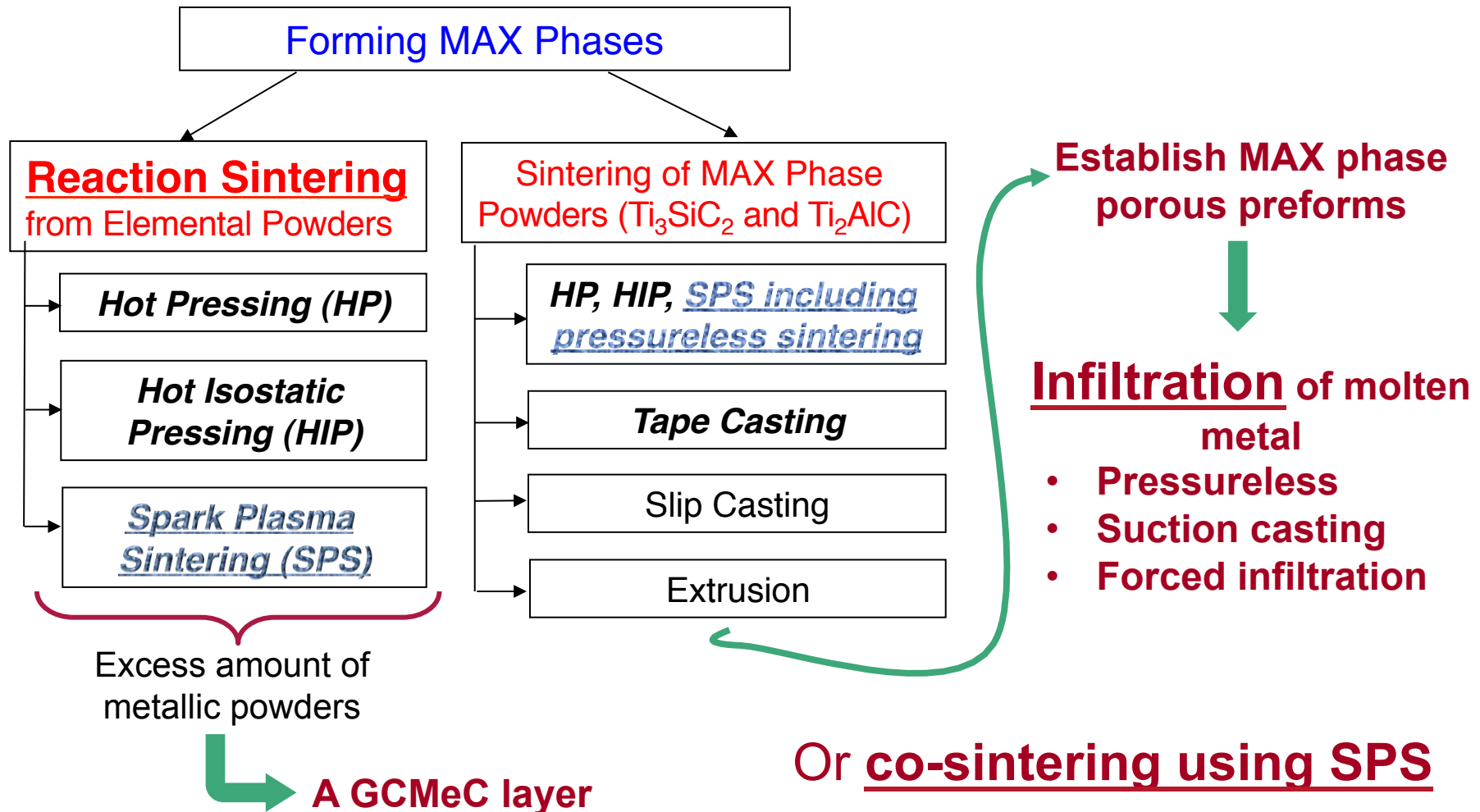
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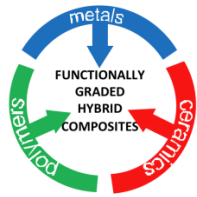
Fabrication of MAX Phases and GCMCs

Materials: Ti_2AlC or Ti_3SiC_2 (MAX phases), Ti and SMAs (NiTi, NiTiPd, MnPd)

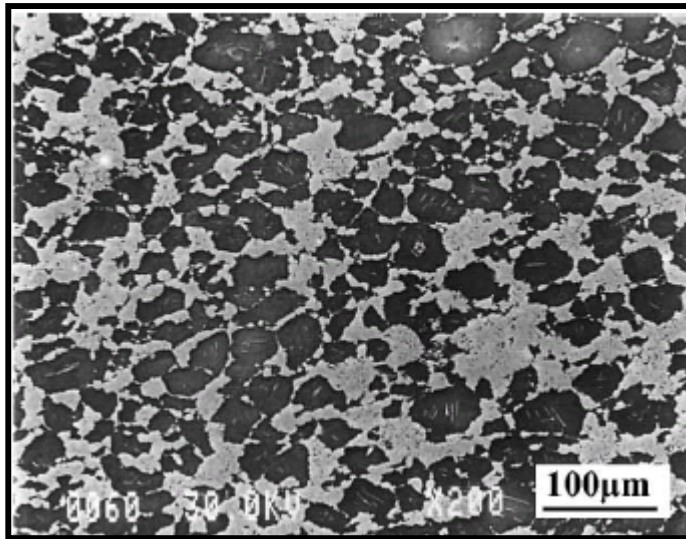


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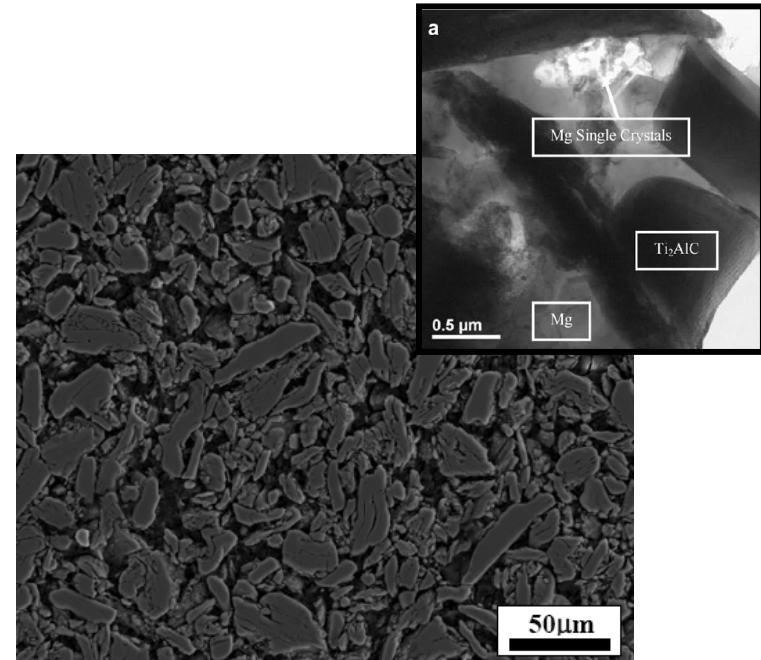


Fabrication of GCMsCs



TiAl/Ti₂AlC composites were produced by spark plasma sintering technology from mixed powders of Ti, Al and TiC.

B. Mei, Journal of Materials Science 75 (2002)



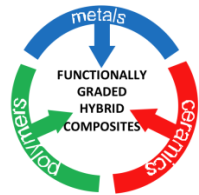
Pressureless melt infiltration of Mg in Ti₂AlC porous perform.

S. Amini, Composites Sci. Tech., 69 (2009)

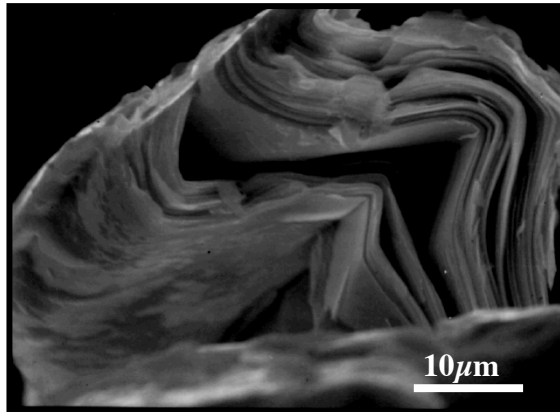


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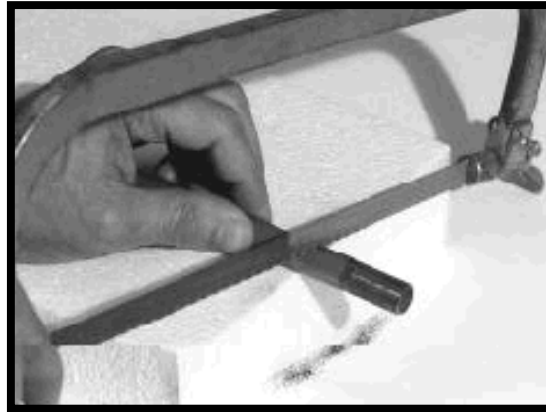




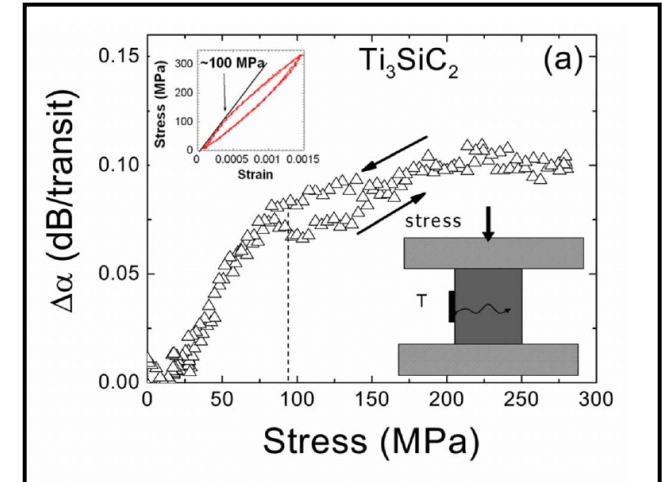
Attributes of MAX Phases and GCMcCs



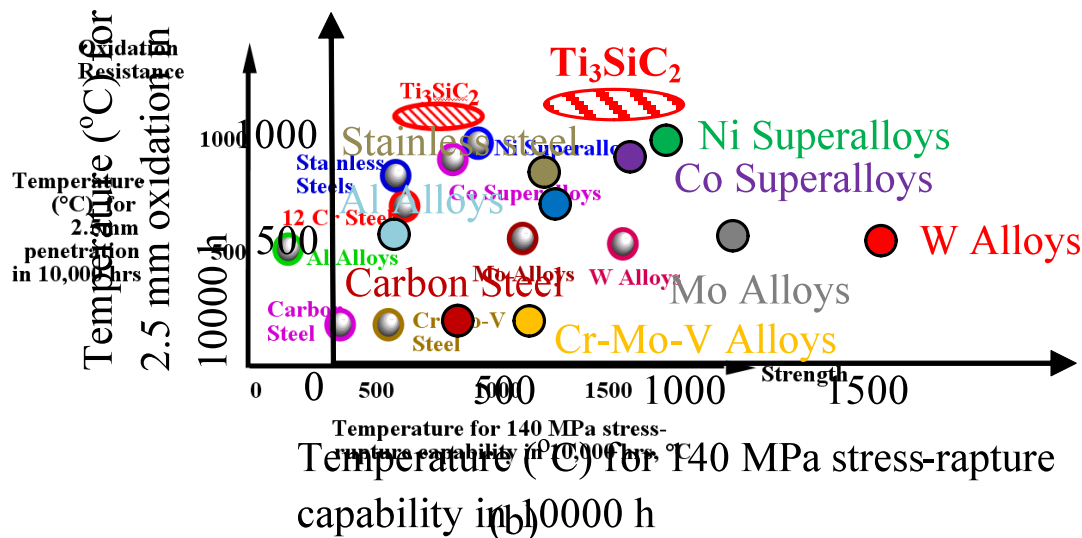
Very good damage tolerance
Large plastic deformation at high temps



Excellent machinability
High stiffness

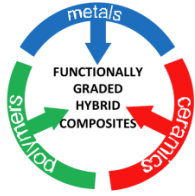


Ultrasound attenuation is a function of the applied load – can be used for stress/health monitoring.



Good combination of mechanical properties and corrosion resistance

Ti based alloys or shape memory materials are expected to have excellent bonding with MAX phases, and provide high damping capacity and compressive stresses imposed at high temperatures due to shape memory effect.



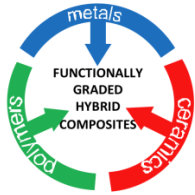
Key Technical Challenges

- Control phase fractions and distribution including gradual change in phase distribution through the thickness;
- Control over phase distribution using different processing approaches:
 - Infiltration
 - Reactive sintering
 - Co-sintering
- Interfacial integrity between metal and ceramic particles and layers
 - Both candidate alloys and ceramics have Ti.
- Long term chemical compatibility between metal and ceramic phases, and between layers with different amount of phases;
- Full infiltration of molten metal into porous MAX phase preform.



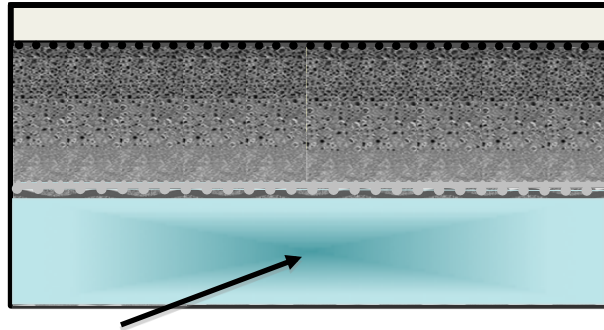
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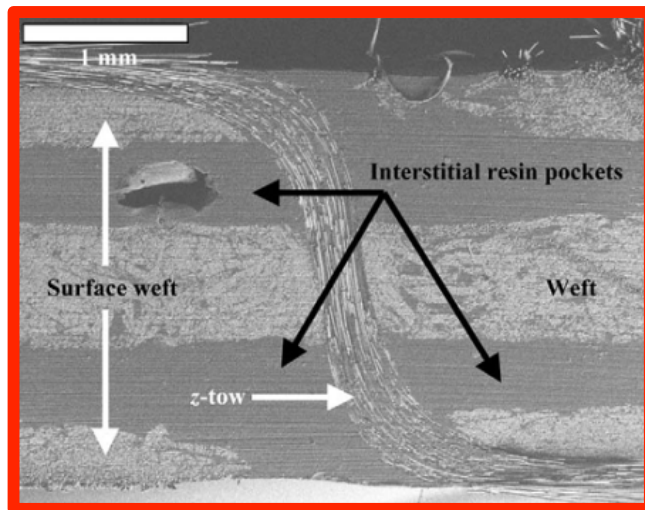


PMC Layer

Actively-Cooled PMCs (AC-PMCs): Microvascular Composites



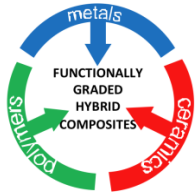
Actively cooled polymer matrix composite (AC-PMC) layer



3-D Woven Microvascular Composites.
3D orthogonally woven monolith with
56% fiber content

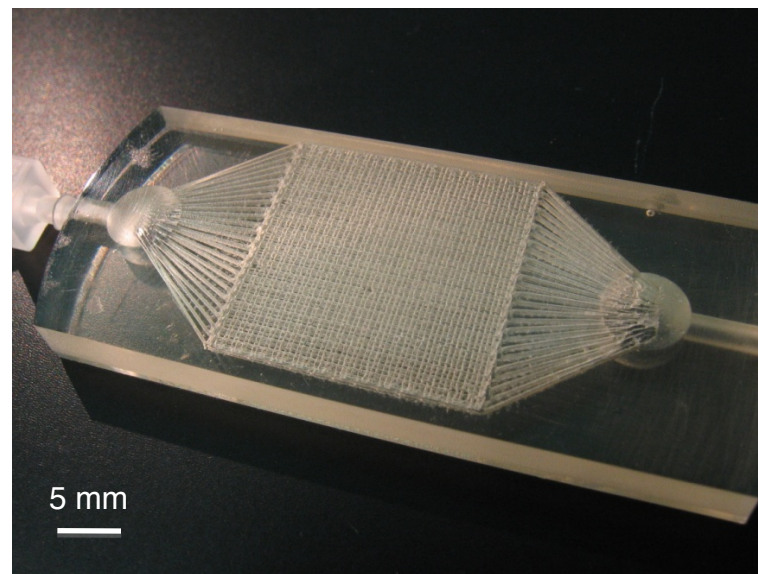
AC-PMC Concepts

- Short term: 2D planar array of embedded microchannels layered within a PMC
- Long term: 3D woven PMC architectures with integrated microvascular networks with sacrificial fibers co-mingled with reinforcement tows



2D Planar Arrays

- Leveraging of preliminary work accomplished under AFOSR MURI on *Microvascular Autonomic Composites* at UIUC

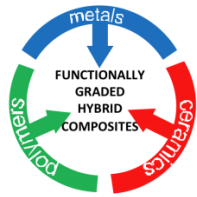


3 x 24 x 200 μm channel grid network

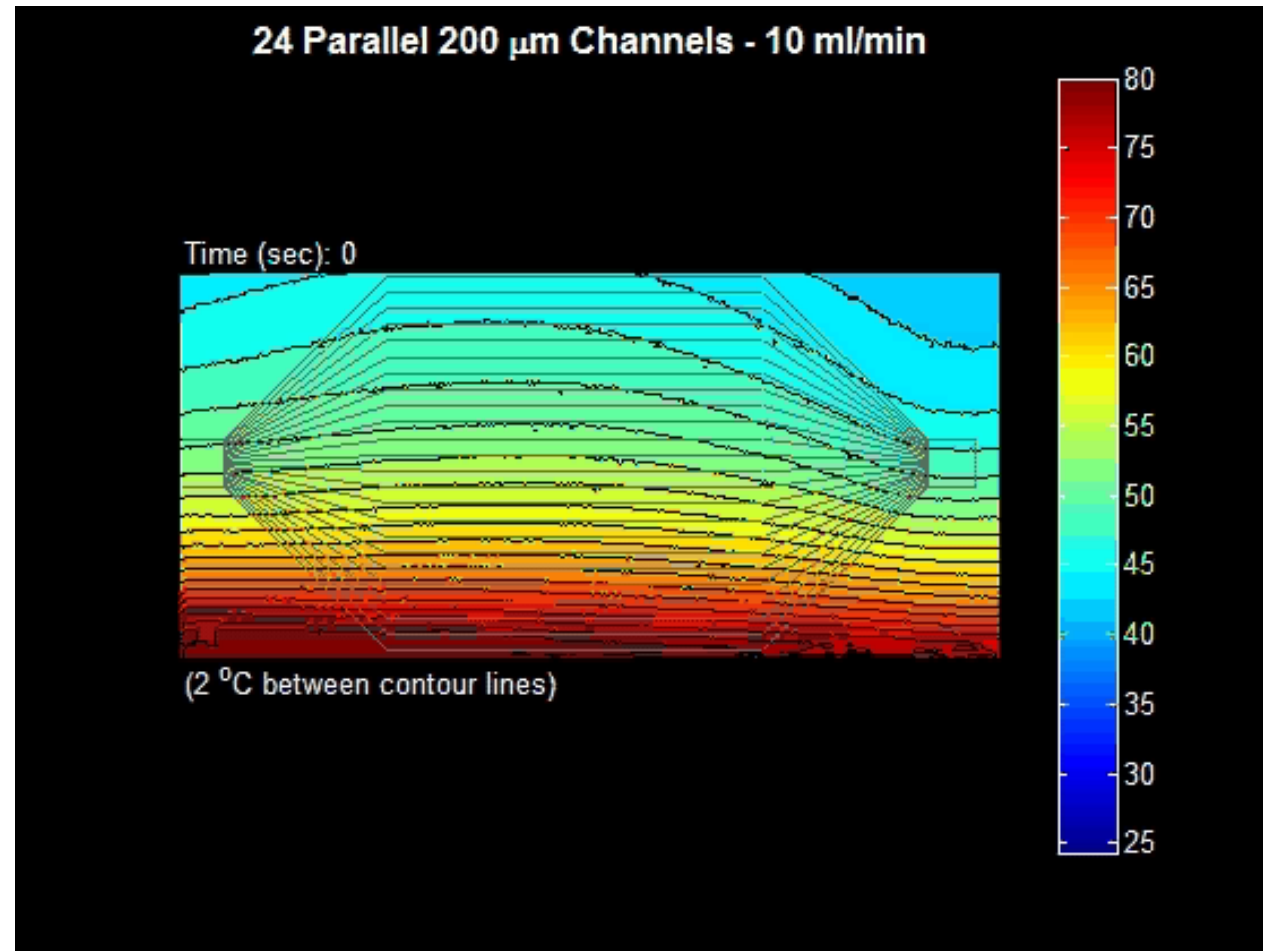


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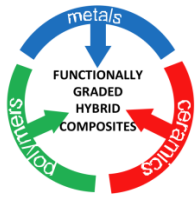


Preliminary Results



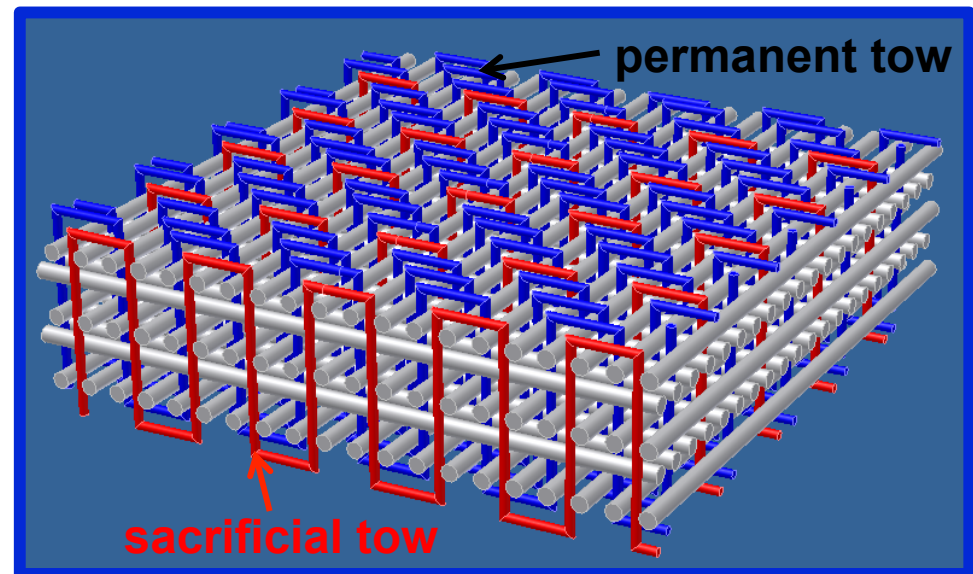
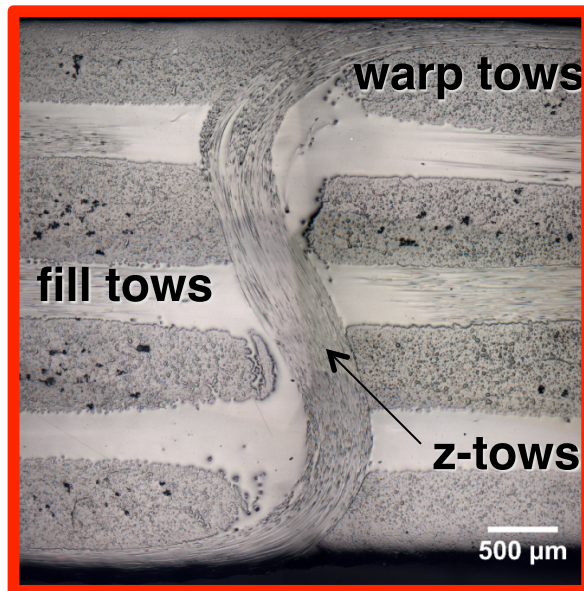
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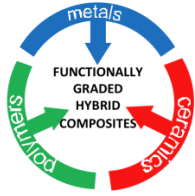


3D Woven PMC

- Microvascular networks embedded in 3D woven PMC that provide active cooling capability
- Sacrificial fibers integrated in z-tows (and/or x- and y-) that are removed during post-cure operation



Schematic of sacrificial fibers integrated with the 3D preform weave



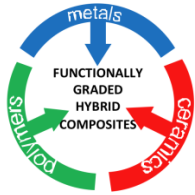
Key Technical Challenges

- *Sacrificial fiber* development
 - Adequate hardness, extensibility, bend strength, etc.
 - Tailorable phase transition for post-cure removal
 - Thermal melt, thermal depolymerization and volatilization, solvent extraction
- Optimization of *vascular network* architectures
 - Easy post-cure removal + high thermal efficiency/low flow resistance
- *Weaving and co-mingling* of sacrificial and structural fibers
 - Collaboration: 3Tex, TEAM
- *Fabrication* of Composites
 - RTM/VARTM
 - Flow characterization and defect analysis (μ -CT, etc.)



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PMC Layer

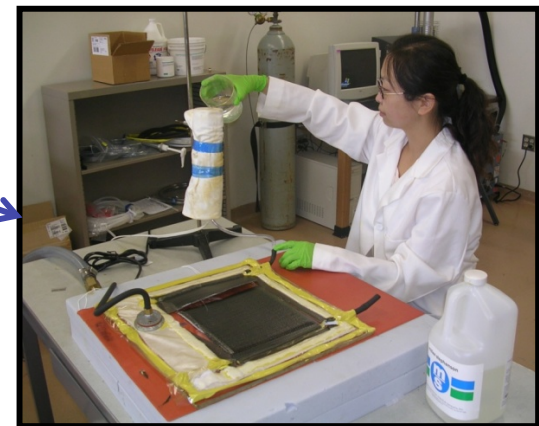
High-Temperature PMCs (HT-PMCs): Polyimide-Based Composites

Approach

- Several polyimide matrices with T_g up to 400 °C including bismaleimide-based polyimides (Maverick Co. and AFRL)
- Available in powder or solution form

Processing  Depending on viscosity:

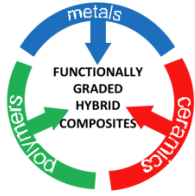
*Solution-cast, Thermal
Cure then Autoclave*



*Solvent-assisted Resin
Transfer Molding*

Advantages

- Polyimides have good thermo-oxidative stability, resistance to moisture absorption, and relatively high moduli.
- Polyimides can withstand hot spikes up to two times their T_g .



Key Technical Challenges

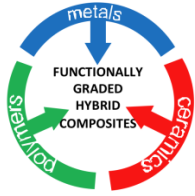
High-Temperature PMCs (HT-PMCs): Polyimide-Based Composites

- Viscosity of aromatic HT polyimides tends to be elevated which makes processing a challenge
 - Solvent-assisted processing of polymer to control viscosity.
- Composite processing by infusing fibers and fabric
 - RTM/VARTM or autoclave for composite processing.
 - Effect on T_g and thermal/structural properties.
- Coupon fabrication using fuzzy glass or fuzzy SiC fibers for SHM



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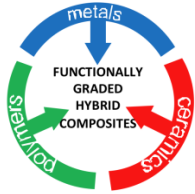
Joining GCMcC and PMC

- The GCMcC/PMC interface consists of bonding the pure metal to the polymer matrix.
- Three joining approaches are adopted:
 - ✓ bonding of metal to PMC using vertical nanocolumns followed by resin infusion,
 - ✓ bonding of metal to an intermediate fabric preform using vertical columns grown on both surfaces, with subsequent infusion of resin,
 - ✓ using Z-pinning technology



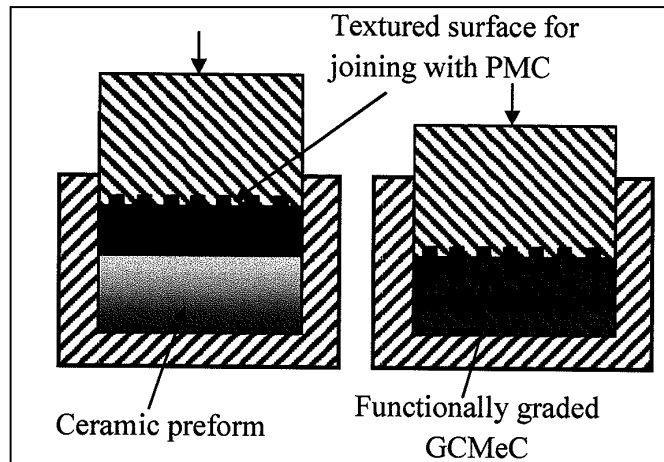
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Joining GCMeC and PMC

Z-Pin Locking

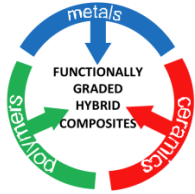


- Metal infiltration in the porous ceramic using a hot press or SPS.
 - Pressing die with small, high aspect ratio holes to create metallic micropillars as Z-pins.
 - Alternately, micromachining to create Z-pins.
- Mechanical locking as the polymer resin is flown on top of the metal layer then cured.



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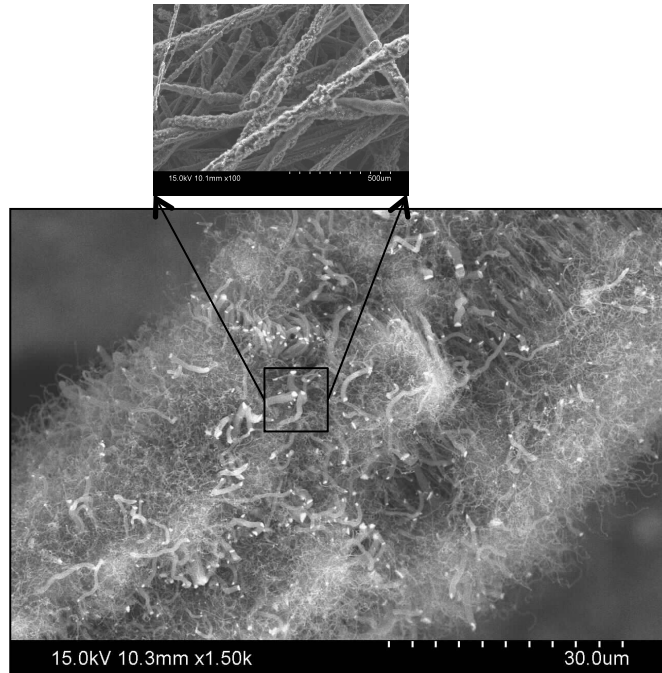




Joining GCMeC and PMC

Vertical Nanocolumns

Vertical nanocolumns are grown forest of carbon nanotubes using CVD.



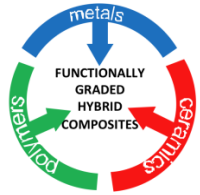
Carbon nanotubes grown on Ni-wire

- 1) Forest will be grown directly on metal layer
 - Polymer will be infused to fill voids between nanotubes
 - Pressing to the rest of composite preform then curing.
- 2) Forest will be grown on metal layer and fiber fabric
 - Polymer will be infused to fill voids between nanotubes
 - Pressing then curing.



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SUMMARY

Collaboration is the key to success

